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AN AMPLITUDE ANALYSIS OF THE $K\bar{K}$ AND $\pi^+\pi^-$ SYSTEMS ($M < 2$ GeV/c^2) PRODUCED IN J/ψ RADIATIVE DECAY*

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Abstract

A mass independent amplitude analysis of the $K\bar{K}$ and $\pi^+\pi^-$ systems ($M < 2$ GeV/c^2) produced in J/ψ radiative decay is presented. For the first time, a large spin zero component in the $\theta(1720)$ mass region is observed, with all data samples analyzed. A small amount of spin two component in this mass region for the $K\bar{K}$ data samples is not ruled out with the present statistics. This study reveals, also for the first time, the production of the $f_0(1400)$ in the $\pi^+\pi^-$ channel, and refines previous measurements of the $f_2(1270)$ and $f_2'(1525)$.

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1. Introduction

In a preliminary amplitude analysis of the MARK III data on the decay $J/\psi \to \gamma K_S K_S$, $J/\psi \to \gamma K^+K^-$, the observation of a dominant spin zero component in the $\theta(1720)$ [1] mass region of the $K\bar{K}$ system was reported [2,3]; consistent results were obtained for the individual decay modes. The analysis has since been extended to the combined data of these two modes, and an analysis of the data from the decay $J/\psi \to \gamma\pi^+\pi^-$ has also been performed. In this report, the results of these analyses are presented, with emphasis on the parameters of the resonances observed in the $K\bar{K}$, $\pi\pi$ systems.

2. The Data Samples

The data were acquired with the MARK III detector at the SPEAR storage ring at SLAC, and correspond to 5.8×10^6 J/ψ events. The procedures followed in defining the event samples are similar to those applied in previous MARK III analyses [4-6]. The $\pi\pi$ invariant mass spectrum for the selected $J/\psi \to \gamma\pi^+\pi^-$ sample is shown as the histogram in Fig. 1; peaks in the mass regions of the $f_2(1270)$ and $\theta(1720)$ are visible, as is a shoulder on the high mass side of the peak at the $f_2(1270)$. The peak at the $\rho(770)$ and a slowly-varying continuum over the whole mass spectrum are also evident; these contributions result from $J/\psi \to \pi^0\pi^+\pi^-$ background events, for which one photon from π^0 decay has very low momentum in the lab frame and thus is often undetected. These background events are simulated using a matrix element determined in a separate study [7] of the selected $J/\psi \to \pi^0\pi^+\pi^-$ data sample. The simulation yields the data points in Fig. 1; the peak at the $\rho(770)$ is successfully reproduced, and a slowly-varying continuum contribution is also obtained.

3. Amplitude Results

The amplitude analysis procedure, and tests thereof, are described in detail in Refs. 2 and 3. The resulting distributions of the amplitude intensities for the combined $K^0\bar{K}^0$ and K^+K^- data, and for the background-subtracted $\pi\pi$ data, are plotted as the data points in Fig. 3; here $a_{J_X\lambda_X}$ denotes the amplitude describing the sequential decay $J/\psi \to \gamma X$, $X \to K\bar{K}$ or $\pi\pi$ with the spin and helicity of X given by J_X and λ_X, respectively. The relative phase angles of the amplitudes are also measured; however, the results are not discussed here, since their uncertainties are very large due to the statistical limitations of the data samples. In the mass region analyzed, only amplitudes corresponding to spin 0 and spin 2 are required in the analysis.

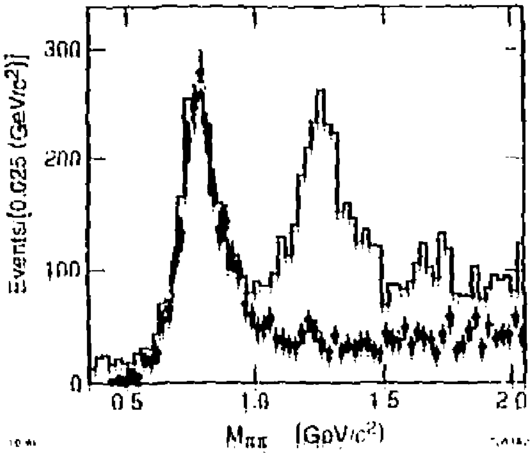

Fig. 1. The $\pi^+\pi^-$ invariant mass distribution for the selected $J/\psi \to \gamma\pi^+\pi^-$ sample (histogram), and for the simulated background events from the decay $J/\psi \to \pi^0\pi^-\pi^+$ (data points). The $K\bar{K}$ mass spectra for the selected $J/\psi \to \gamma K^+K^-$ and $J/\psi \to \gamma K_S K_S$ samples are shown in Refs. 3 and 3.

4. Resonance Parameters and Branching Fractions

The solid curves in Fig. 2 correspond to fits of coherent superpositions of individual Breit-Wigner resonances (broken curves) to the data points of each intensity distribution. Contributions due to the resonances $f_2(1270)$ and $f_2'(1525)$, and to resonances in the $f_0(1400)$ and $\theta(1720)$ mass regions are included. The mass and width of the $f_2(1270)$ and $f_2'(1525)$ are fixed at the values quoted in the Particle Data Book [9], while those of the S-wave resonances are to be determined. The fits yield $M = 1440 \pm 20$ MeV/c^2, $\Gamma = 160 \pm 40$ MeV/c^2 for the $f_0(1400)$, and $M = 1710 \pm 20$ MeV/c^2, $\Gamma = 186 \pm 30$ MeV/c^2 for the $f_0(1710)$, the latter being the S-wave resonance in the $\theta(1720)$ region; the errors are purely statistical. It follows from these results that the shoulder in the $\pi^+\pi^-$ mass distribution above the $f_2(1270)$ (cf., Fig. 1) is due to the production of the $f_0(1400)$, and not to an $f_2(1270)$–$f_2'(1525)$ interference effect, as previously speculated [5,8]. In order to estimate the contribution of a possible spin-2 resonance in the $\theta(1720)$ mass region in the $K\bar{K}$ data, an $f_2(1710)$ is included, with mass and width fixed to those of $f_0(1710)$.

The branching fractions $B(J/\psi \to \gamma X, X \to K\bar{K}$ or $\pi\pi)$ obtained for each resonance "X" and for each helicity amplitude are listed in Table 1; the first

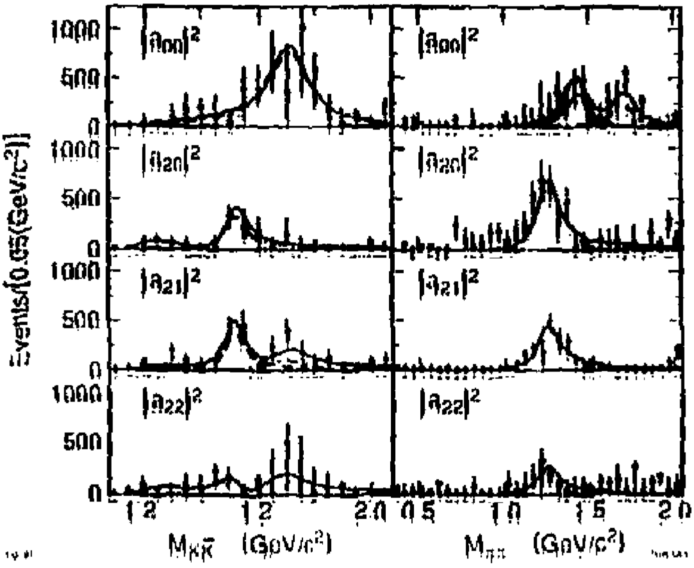

Fig. 2. The amplitude intensity distributions for (a) the $K\bar{K}$ data, (b) the $\pi\pi$ data; the data points indicate the measured amplitude intensities; the solid curves correspond to fits of coherent superpositions of Breit Wigner resonances (broken curves) to the data points in each amplitude intensity distribution.

error is statistical and the second is systematic. The systematic error includes the uncertainty in the number of J/ψ events (8.5%), and that due to the analysis procedure (10%). The latter is estimated by varying the event selection criteria and the mass binning, and by taking account of events from one amplitude wrongly attributed to another due to solution ambiguities.

Monte Carlo studies have shown that events from the a_{22} amplitude can feed into other amplitudes. This contamination is larger when the other amplitudes are small; indeed a mathematical solution ambiguity occurs when the contributions of the other amplitudes vanish. The ambiguity associated with this amplitude has also been pointed out by Yan [10], whose conclusions are consistent with those above. However, for the real data, this ambiguity is not significant, and the results obtained from multiple independent fits in each mass bin are quite consistent. In addition, a check is made of the maximum number of spin 0 $J/\psi \to \gamma K^+K^-$ events for the mass region (1.675 to 1.775) GeV/c^2, which might result from misidentified spin 2 contributions. This is done by applying the analysis procedure to Monte Carlo samples generated with amplitude values obtained for the real data in this mass region with pure spin 2 amplitudes. The average fraction of events misidentified as

S wave is found to be 11.7%, this is significantly less than the fraction of spin 0 real events (74%); this test clearly establishes that the spin 0 enhancement in the $\theta(1720)$ mass region is real, and does not result from the misidentification of spin 2 contributions.

Table 1. Preliminary $Bf(J/\psi \to \gamma X, X \to K\bar{K}$ or $\pi\pi) \times 10^4$.

	$f_0(1400) \to K\bar{K}$	$f_0(1710) \to K\bar{K}$	$f_0(1400) \to \pi\pi$	$f_0(1710) \to \pi\pi$
$\lvert a_{00}\rvert^2$	$0.05 \pm 0.16 \pm 0.01$	$6.47 \pm 1.14 \pm 0.84$	$2.69 \pm 0.60 \pm 0.45$	$1.94 \pm 0.60 \pm 0.35$
	$f_2(1270) \to K\bar{K}$	$f_2'(1525) \to K\bar{K}$	$f_2(1710)(?) \to K\bar{K}$	$f_2(1270) \to \pi\pi$
$\lvert a_{20}\rvert^2$	$0.50 \pm 0.13 \pm 0.06$	$1.48 \pm 0.26 \pm 0.19$	Not included	$6.34 \pm 0.43 \pm 0.82$
$\lvert a_{21}\rvert^2$	$0.16 \pm 0.06 \pm 0.13$	$1.60 \pm 0.29 \pm 0.20$	$0.66 \pm 0.22 \pm 0.09$	$4.13 \pm 0.26 \pm 0.54$
$\lvert a_{22}\rvert^2$	$0.24 \pm 0.10 \pm 0.13$	$0.37 \pm 0.34 \pm 0.05$	$1.36 \pm 0.62 \pm 0.18$	$2.40 \pm 0.28 \pm 0.41$

Using the results in Table 1, the amplitude intensity ratios and the total branching fractions for the tensor resonances are as listed in Table 2.

Table 2. Preliminary amplitude intensity ratios and total branching fractions

	$f_2'(1525) \to K\bar{K}$	$f_2(1270) \to K\bar{K}$	$f_2(1270) \to \pi\pi$
$(\lvert a_{21}\rvert^2 / \lvert a_{20}\rvert^2)$	1.08 ± 0.31	0.32 ± 0.28	0.65 ± 0.13
$(\lvert a_{22}\rvert^2 / \lvert a_{20}\rvert^2)$	0.25 ± 0.24	0.48 ± 0.36	0.38 ± 0.06
$Bf \times 10^4$	$3.45 \pm 0.52 \pm 0.28$	$0.90 \pm 0.11 \pm 0.07$	$12.85 \pm 0.57 \pm 1.03$

Although the amplitude ratios for the $f_2(1270)$ obtained from the $K\bar{K}$ mode are poorly measured, they agree within error with those obtained from the $\pi\pi$ mode, as they should.

5. Conclusion

For the first time, a large spin zero component in the $\theta(1720)$ mass region has been observed in J/ψ radiative decay to $K\bar{K}$ and $\pi^+\pi^-$. This is attributed to the production of an S wave resonance, the $f_0(1710)$, of mass and width $M = 1710 \pm 20$ MeV/c^2, $\Gamma = 186 \pm 30$ MeV/c^2, respectively, with branching fractions to $\pi\pi$ and $K\bar{K}$ in the ratio 0.30 ± 0.12. The presence of a small amount of spin two component (~24%) in this mass region for the $K\bar{K}$ data cannot be ruled out with the present statistics. This study also reveals, for the first time, the production of the $f_0(1400)$, with mass and width measured to be $M = 1440 \pm 20$ MeV/c^2, $\Gamma = 160 \pm 10$ MeV/c^2 respectively, and demonstrates that the shoulder in the $\pi^+\pi^-$ mass distribution above the $f_2(1270)$ (cf., Fig. 1) is due to the production of this state, and not to an $f_2(1270)$–$f_2'(1525)$ interference effect, as previously speculated [5,8]. The previous measurements of the $f_2(1270)$ and $f_2'(1525)$ have been refined in the present analysis with the simultaneous inclusion of spin 0 and 2 amplitudes in the fit. The ratios of the spin 2 amplitude intensities of the $f_2'(1525)$ are found to be $(|a_{21}|^2/|a_{20}|^2) = 1.08 \pm 0.31$ and $(|a_{22}|^2/|a_{20}|^2) = 0.25 \pm 0.31$, while those of the $f_2(1270)$ take the values $(|a_{21}|^2/|a_{20}|^2) = 0.65 \pm 0.13$ and $(|a_{22}|^2/|a_{20}|^2) = 0.48 \pm 0.08$. The experimental results for the $f_2'(1525)$ and $f_2(1270)$ thus agree within error, although it must be acknowledged that the $f_2'(1525)$ uncertainties are large. Furthermore, these results are in good agreement with the predictions of Krammer [11]. On the other hand, while Close and Li [12,13] predict that $(|a_{21}|^2/|a_{20}|^2) \cong 0.8$, in agreement with the present measurements, their prediction that $(|a_{22}|^2/|a_{20}|^2) \cong 0$ disagrees with the result obtained for the $f_2(1270)$ in the present analysis.

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